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Appropriate metrics to inform farmers about species diversity

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Abstract

Farmers are key players in actions to halt biodiversity loss from farmland. However, if farmers are to sustain biodiversity, they must first be adequately informed about biodiversity and understand its drivers. Measuring biodiversity at the farm scale is difficult because of the structural complexity of many farms, and because different aspects of diversity can be considered desirable, e.g. species richness or rarity. In this study we examined 19 grassland farms in Central Switzerland, and sampled plants, earthworms, spiders and bees using a stratified sampling design. We considered several metrics of species diversity, but found two particularly useful at farm scale: average richness (area-weighted) and farm uniqueness in terms of species identity. Average richness reflects the expected species richness in a random sample taken on the farm, and farm uniqueness is the contribution of a farm to the total species richness of all farms under study. Average richness and farm uniqueness are complementary and reflect different aspects of biodiversity. We demonstrate how combining these metrics enables tailored recommendations for enhancing species diversity on the farm.

Keywords

Plant; Earthworm; Spider; Bee; Agricultural management; Farmland habitat

1. Introduction

Agriculture is the main land use in Europe and around 50% of wildlife species are linked to farm habitats (Kristensen, 2003). Changes to these habitats through agricultural intensification have caused populations of many farmland species to decrease critically (Benton et al., 2003), and this loss can impair important ecological functions (Hooper et al., 2005). To remedy this situation, new financial incentives for biodiversity-friendly farming have been introduced into agricultural policy. However, when evaluated, the measures implemented so far have only been partly successful (ECA, 2012; Kleijn et al., 2006). On the one hand, this may be due to ecological reasons. The measures were beneficial, e.g. for certain taxonomic groups but not for rare species (Aviron et al., 2009) or in simple landscapes but less so in complex ones (Batáry et al., 2011). In addition, processes require time until effects can be observed. On the other hand, farmers tend not to give priority to such measures even with financial incentives (Siebert et al., 2006). They may hesitate to implement measures that are imposed by authorities because of entrepreneurship infringement and administrative overload (Clark and Murdoch, 1997). However, the majority of farmers appreciate nature, sense an environmental stewardship and see advantages of ecological functions supplied by biodiversity for their work, e.g. soil fertility, pollination and biological control of pests (Sullivan et al., 1996). Biodiversity is also often associated to other natural resources such as water, soil and air of which farmers acknowledge the need of protection (Fischer and Young, 2007). A dialogue between farmers and researchers on biodiversity was shown to be much more promising than a top-down strategy with excessive control by authorities (Siebert et al., 2006). Farmers generally have a comprehensive view on their land and know how habitats develop and react to agricultural management. In contrast, researchers survey populations of little noticed organisms and assess their contribution to the ecological network. Cooperative approaches hence value the local knowledge of farmers about their land and the environment, as well as scientific evidence in a way that they are useful in agricultural practice.

Farmers are generally experienced at making complex decisions by weighting up multiple sources of external information. This can be the expected market price, cost of machinery and labour, which farmers combine with their personal experience and spatial and climatic constraints to decide on farm structure and management practices (Ahnstrom et al., 2009; Brady et al., 2012; Kelemen et al., 2013). We assume that if better quantitative information about biodiversity, its underlying drivers and its benefits was provided to farmers, they would integrate such information into their management decisions (Home et al., 2014). Therefore, we explore ways of summarizing this quantitative information by appropriate metrics of species diversity.

Selecting robust metrics of species diversity on farms presents a number of substantial challenges. (i) The metrics must be simple, transparent and easy to communicate to farmers and other stakeholders. (ii) Farmers should be able to compare their farm with colleagues' farms and assess their relative performance. They also need to know how management practices are linked to species diversity so that they can enact appropriate measures. (iii) Species diversity has multiple aspects. Goals might be to promote as many species as possible and to preserve rare species (Gaston, 1996). Given that a comprehensive assessment of species diversity at the farm level is not feasible, a single metric is unlikely to be sufficient

(Büchs, 2003). (iv) Farms are economic rather than ecological units and they differ in size and spatial arrangement. Farms include areas directly managed for production and other habitats such as field edges or hedgerows, which are managed by farmers but without the direct aim of production. An appropriate metric should be applicable at the whole-farm scale and therefore needs to rely on stratified sampling to provide adequate coverage of different habitats (Kindt and Coe, 2005). To sum this up, important criteria to select metrics are that they are easy to understand, comparable among farms, and that they are adapted to the levels of biodiversity and to the complexity of farm structures.

In this study, we investigated whether two complementary metrics of species diversity satisfy the criteria outlined above. We assessed the diversity of four contrasting taxonomic groups, i.e. plants, earthworms, spiders and bees, in a mountainous region in Central Switzerland consisting of grassland-based farms. The four taxonomic groups were selected because they are involved in a range of ecological services and occupy different trophic levels. Due to their different mobility and life strategies, they also potentially indicate both, short- and long-term changes of the environmental conditions. The metrics are (1) the average number of species observed in the different habitats of the farm, weighted by the area of these habitats (after Tasser et al., 2008), and (2) the uniqueness of the farm with respect to the species occurrences in the region (after Wagner and Edwards, 2001). Each farm was positioned relative to the regional average of richness and uniqueness of the four taxonomic groups.

2. Methods

2.1. Data collection

2.1.1. Study region and farms

The study region covered 12 km^2 and was located in Central Switzerland, in the Northern Swiss Alps (46°54’N, 8°12’E). The mean annual temperature in the region is 5.6°C, and the average annual precipitation is 1300 mm. The majority of land is grassland for dairy production and breeding. Average slope of farmland is 28%, and 90% of the fields have slopes between 11% and 50%. Soils consist of flysch, sandstones and shale. Of the 66 farms in the region, 19 were randomly selected for the investigation presented here: ten of these were under organic and nine under non-organic management. The farms were located between 605 and 1133 m asl (Arndorfer et al., 2010) and ranged in size between 4 and 20 hectares (on average 10 hectares). The farm unit was defined as the total utilized agricultural area, which included unfarmed habitats such as hedgerows and small copses <800 m^2. Farm buildings, private gardens and forests >800 m^2 were excluded.

2.1.2. Habitat mapping and species sampling

Habitats on each farm were distinguished based on Raunkiær plant life forms, environment and management (Bunce et al., 2008; Raunkiær, 1934). We mapped both areal (at least 5 m wide and covering 400 m^2) and linear habitats (at least 0.5 m wide and 30 m long). We identified 19 different habitat types (12 areal habitat types, 7 linear habitat types; see Appendix A in Supplementary material), and we then surveyed one randomly-selected example of each habitat type on each farm. In total, 139 habitats (4 – 12 habitats per farm) were surveyed (Fig. 1).

In each selected habitat, we sampled species of the four taxonomic groups: plants, earthworms, spiders and bees (wild bees and bumblebees) from spring to early autumn 2010 (Dennis et al., 2012). Plant surveys were conducted on 10 m × 10 m squares for areal habitats and 1 m × 10 m plots for linear habitats. We recorded all species and estimated their respective cover. Earthworms were collected at three random locations per habitat by pouring a solution of allyl isothiocyanate (0.1 g/l) into a metal frame of 30 cm × 30 cm to encourage earthworms to the surface. Subsequently, we sorted a 20 cm deep soil-core by hand.

Identification and counting of earthworm species was conducted in the lab. Non clitellates (juveniles and sub-adults) were excluded from the analysis. Spiders were sampled at three dates during the season on five circular areas of 35.7 cm diameter per habitat using a modified leaf blower to suck the spiders from the surface. The samples were frozen on the spot and adults were identified in the lab. Bees were captured during good weather conditions - i.e. during periods of sunshine when it was not too windy and the temperature was higher than 15°C - on three dates with a handheld net along a 100 m x 2 m transect for 15 min. Honeybees (*Apis mellifera*) were excluded from the analysis. Species of all four taxonomic groups were identified to the species level by specialists.

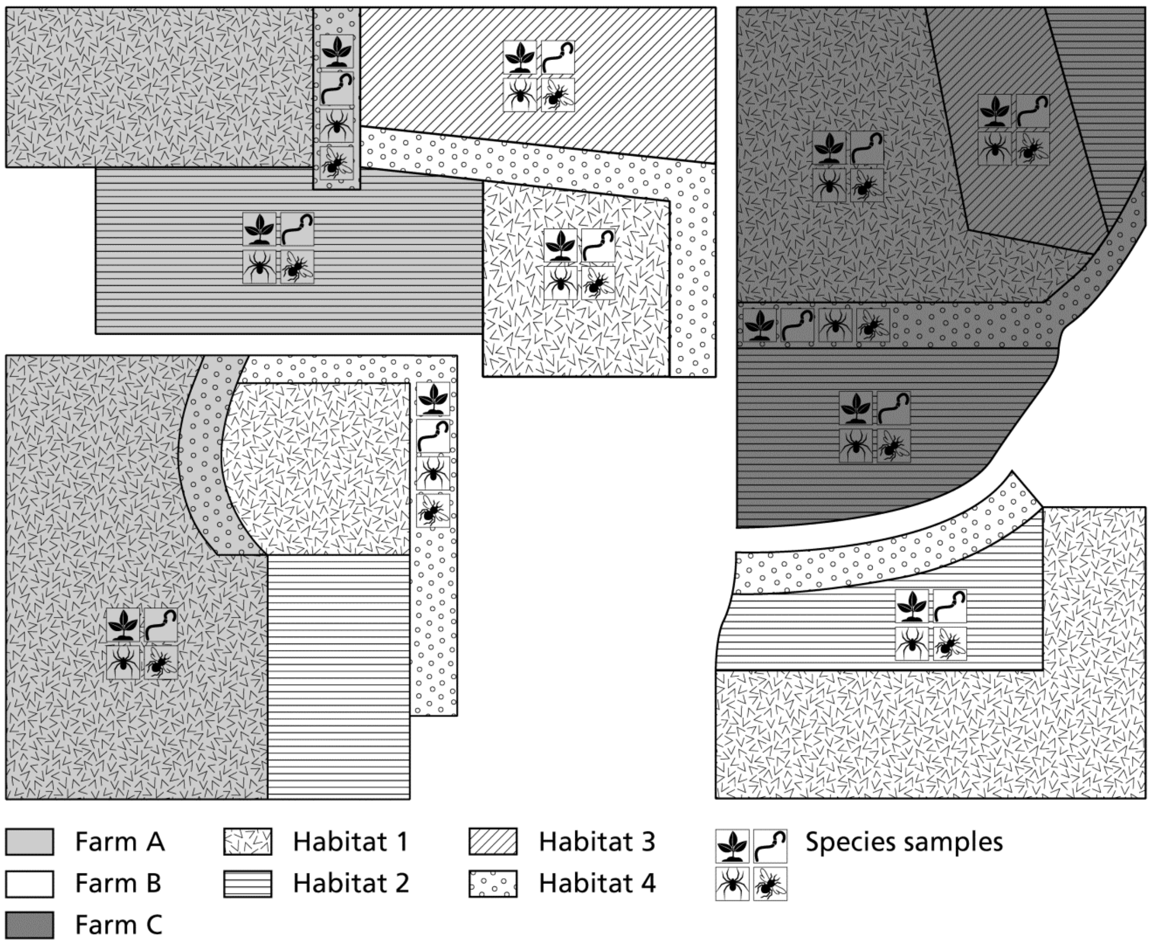

Fig. 1: Schematic representation of the sampling design for three exemplary farms. Farms are indicated by different shading. Each farm consists of different habitat types, indicated by different fill patterns. Species symbols indicate the randomly selected fields where plant, earthworm, spider and bee species were sampled.

2.1.3. Information about farms, management practices and habitat characteristics

Farmers were informed about the study and invited to participate by letter and phone calls or personal meetings. During a first visit on the farm, they explained the configuration of the farm to provide a basic matrix for the habitat mapping. After the field work, information of management practices in all habitats investigated was collected in face-to-face interviews with farmers, lasting 1.5 – 3 h. The interviews followed a standardized questionnaire and focused on management frequencies, inputs and general farm characteristics. Out of this information, we calculated management variables at the farm scale (e.g. the average nitrogen input per hectare). Farmers' motivation and attitudes regarding biodiversity were not recorded. Further, data from the habitat mapping were used to calculate farm-specific habitat characteristics such as the number of areal habitat types or the average habitat size (Herzog et al., 2012).

2.2. Calculation of average richness per farm and farm uniqueness

The average richness of the *j*th farm (*AR*) was calculated as

$$AR_j = \sum_h R_{hj} * \frac{A_{hj}}{A_j} \tag{1}$$

where R_{hj} is the number of species found in the sampled habitat of type h (h = 1, 2, …, n_j) in farm j (j = 1, 2, ..., 19). A_{hj} is the sum of the area of all habitats of type h in farm j and A_j is the total area of farm j.

The uniqueness of the *j*th farm (*FU*) was calculated as

$$FU_j = \sum_i \frac{\omega_j \overline{x_{hij}}}{\sum_j \omega_j \overline{x_{hij}}} \tag{2}$$

where $\overline{x_{hij}}$ is the mean abundance of species i in farm j per habitat type h on the farm j, and ω_j is the number of habitat types in farm j, n_j, divided by the total number of habitats sampled in the study area (Wagner and Edwards, 2001; see Appendix B in Supplementary material for an example of the calculation for three farms). In addition to the original reference, we added the term *h* to Eq. (2) for analogy to Eq. (1).

2.2.1. Normalization of average richness and farm uniqueness

To provide values of average richness and farm uniqueness that are comparable among different taxonomic groups, we divided each metric by the arithmetic mean across all farms.

For each taxonomic group per farm, average richness and farm uniqueness were first calculated separately. We then calculated the mean average richness over the four taxonomic groups per farm and the mean farm uniqueness over the four taxonomic groups per farm. Finally, the total mean was the average of the mean average richness and the mean farm uniqueness per farm.

2.3. Data analysis

We conducted all data analyses with R 2.15.3 (R Development Core Team, 2012).

2.3.1. Correlations and clustering

To assess the degree to which our two metrics, average richness and farm uniqueness, provide the same information, we correlated these values across farms. Therefore, we first assessed correlations between average richness and farm uniqueness for each taxonomic group in turn, and then assessed correlations between the four taxonomic groups within average richness and farm uniqueness, respectively.

Further, we conducted a cluster analysis to allocate farms to three groups with similar characteristics regarding mean values of average richness and farm uniqueness per taxon, and the total mean over all four taxonomic groups. Partitioning around medoids (R package cluster 1.14.3), which is a robust method of unsupervised divisive classification, was applied.

The result was in agreement with the visual consultation of a non-metric multidimensional scaling using vegan 2.0-6.

2.3.2. Regression analyses

Linear regression was used to explain average richness and farm uniqueness. In order to avoid problems of collinearity, a subset of all available explanatory variables was selected based on ease of interpretation and low variance inflation factors (Borcard et al., 2011). Five of the ten selected variables described management practices: the management system (organic vs. non-organic), the average stocking rate per hectare forage area, total expenditures (on fertiliser, crop protection and concentrate feed stuff), the average nitrogen input per hectare (nearly exclusively organic nitrogen) and the average number of mechanical operations. The other five explanatory variables described habitat characteristics of the farm: the number of different areal habitat types, the number of different linear habitat types, the average habitat size, the length of linear elements containing woody structures per hectare of farm area and the Shannon diversity index of the habitats per farm. All these explanatory variables were meaningful because farmers are able to influence them (e.g. more or less intensive use of certain habitats, creating or removing new habitats such as hedgerows).

Since both metrics, average richness and farm uniqueness, of the four taxonomic groups satisfied the normality assumption for residuals, linear regression models were estimated with ordinary least squares. Model selection was undertaken using Akaike’s information criterion corrected for small samples (Burnham and Anderson, 2002). The significance of effects was assessed using likelihood-ratio tests. Interactions among the explanatory variables were tested, but they did not improve the model fit.

2.4. Calculation of average richness per habitat category and habitat uniqueness

Because of their sparsity within farms, habitats had to be aggregated into four broad categories in order to make comparisons at habitat level useful. The categories were: intensively managed areal habitats (e.g. frequently fertilized and cut grassland), low-input areal habitats (e.g. dry meadows), herbaceous linear habitats (e.g. unpaved tracks) and linear habitats with woody structures (e.g. hedgerows). Detailed information on the grouping is provided in Appendix A, in Supplementary material S.1. Traditionally managed orchards were included in the category intensively managed areal habitats as they were mainly on intensive grassland. For each habitat category, we calculated average richness and habitat uniqueness using equations 1 and 2 (with $j = 1, ..., 4$ being the habitat categories). To allow comparisons between taxonomic groups, we normalized average richness and habitat uniqueness per habitat category.

3. Results

In 139 sampled habitats on 19 farms, we found 280 plant species, 16 earthworm species (2975 adult individuals), 133 spider species (2802 adult individuals) and 65 wild bee and bumblebee species (763 individuals). The number of species found in a single habitat varied with taxonomic group. For plants the number of species per habitat ranged from 9 to 70 (mean = 34); earthworms ranged from 1 to 10 (mean = 6); spiders ranged from 3 to 20 (mean = 8) and bees ranged from 0 to 10 (mean = 4).

3.1. Evaluation of average richness per farm and farm uniqueness

Average richness and farm uniqueness were uncorrelated for the majority of taxonomic groups except for plants, where a significant correlation was found (Table 1). Generally, farms showed different rankings for the four taxonomic groups and this was reflected in missing correlations between the groups. An exception was the positive correlation between the farm uniqueness of plants and bees.

Table 1: Correlations between and within average richness and farm uniqueness. Fields with grey background: correlations between average richness and farm uniqueness for each taxonomic group. Upper panel: correlations between the average richness of the four taxonomic groups. Lower panel: correlations between the farm uniqueness of the four taxonomic groups (r = Pearsons's correlation coefficient, p = p-value). Significant correlations are printed in bold.

	Plants		Earthworms		Spiders		Bees	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Plants	**0.483**	**0.036**	-0.247	0.307	0.311	0.195	0.241	0.320
Earthworms	0.427	0.068	0.158	0.517	-0.396	0.093	0.104	0.671
Spiders	0.447	0.055	0.116	0.638	0.104	0.672	0.032	0.896
Bees	**0.651**	**0.003**	0.264	0.275	0.095	0.698	0.212	0.382

Normalizing average richness and farm uniqueness allowed comparisons across the four taxonomic groups even when the groups differed substantially in absolute magnitude (Fig. 2a – e). Average richness was less variable among farms than farm uniqueness (Standard deviations of average richness and farm uniqueness were 0.185 and 0.539 for plants, 0.180 and 0.391 for earthworms, 0.202 and 0.465 for spiders and 0.338 and 0.516 for bees, respectively).

Cluster analysis resulted in groups of farms with the following characteristics. One group (Fig. 2; circles around farm letters) consisted of farms with a medium average richness and a low farm uniqueness. These farms were generally habitat-poor (4 – 6 habitats per farm). A second group (Fig. 2; quadrates around farm letters) was average for both metrics. These farms varied in the number of different habitat types (5 – 11). The third group of farms (Fig. 2; diamonds around farm letters) had high values for average richness and for farm uniqueness. Most of these farms had a high number of different habitat types (9 – 12, except farm O with only 7 different habitat types).

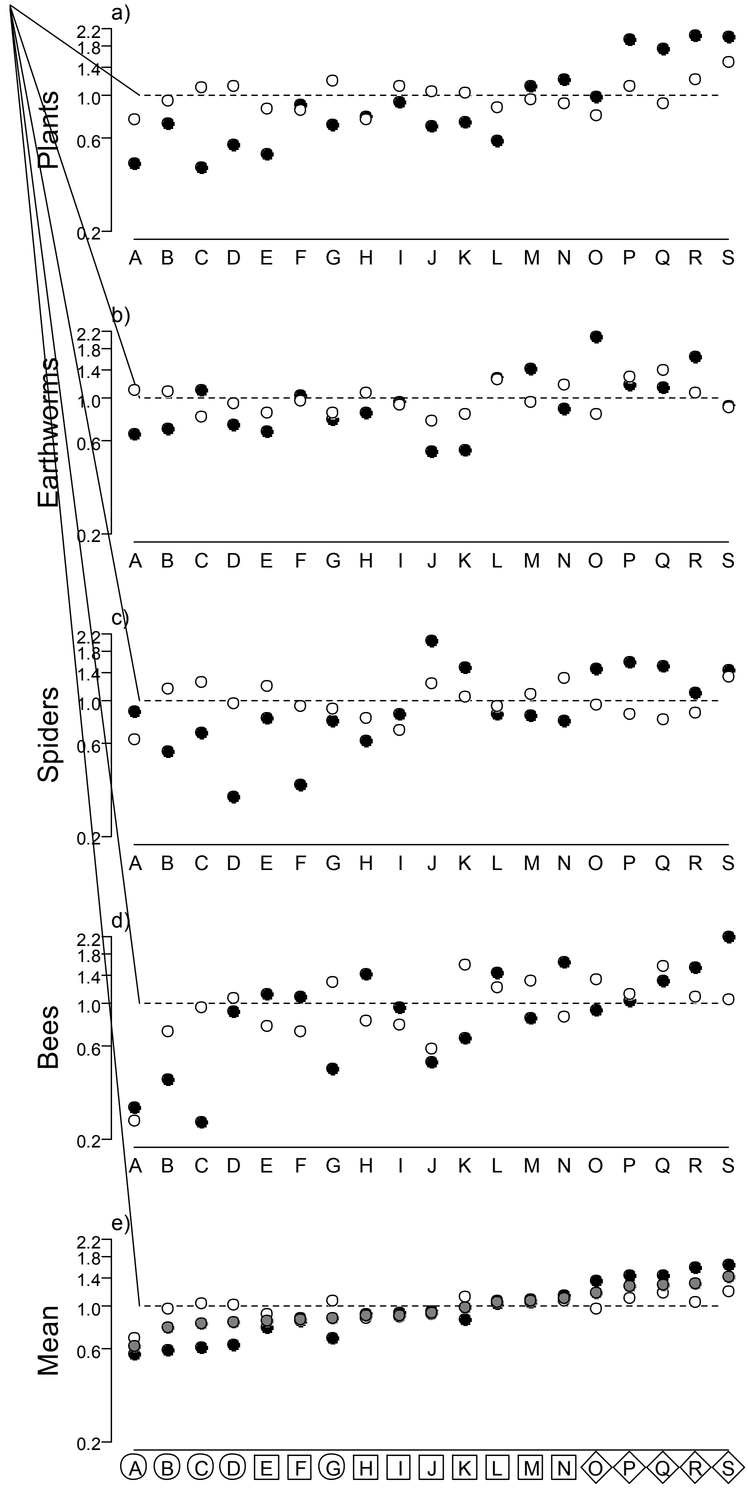

Fig. 2: Species diversity metrics of 19 study farms. Average richness (open circles) and farm uniqueness (filled circles) for (a) plants, (b) earthworms, (c) spiders and (d) bees of farms A to S are shown relative to the average of all 19 farms (dashed line). Panel (e) shows the mean average richness over the four taxonomic groups (open circles), the mean farm uniqueness over the four taxonomic groups (filled circles) and the total mean (grey circles). The *y*-axis is log-scaled to equalize distances below and above the average mean. Farms are ordered according to the total mean. Circles, quadrats and diamonds around farm letters show the grouping of the farms according to a cluster analysis.

3.2. Effects of management practices and habitat characteristics

Eight out of ten tested explanatory variables had a significant effect on average richness and/or farm uniqueness for at least one taxonomic group (Table 2). No significant effects were found for the length of linear elements with woody structures per hectare and the Shannon diversity index of the habitats.

Average richness of plants and bees were negatively affected by the number of mechanical operations (Table 2a). Average richness of earthworms significantly increased with nitrogen input, the number of areal habitat types and the average habitat size. By contrast, average richness of spiders tended to decrease with the average size of habitats.

Farm uniqueness of plants was significantly increased by the number of different areal habitat types (Table 2b). Farm uniqueness of earthworms was lower on organically managed farms than on non-organically managed farms, and the average stocking rate had a significantly negative effect on farm uniqueness of earthworms. Farm uniqueness of spiders was significantly higher on farms with an increased number of linear habitat types. Farm uniqueness of bees was higher on organically managed farms than on non-organically managed ones. The expenditures (on fertiliser, crop protection and food stuff), the nitrogen input and the average size of habitats had a significant negative effect on farm uniqueness of bees.

The mean average richness over all four taxonomic groups was significantly decreased by the number of mechanical operations (Table 2c). The mean farm uniqueness over all four taxonomic groups and the total mean were both significantly increased by the numbers of areal and linear habitat types.

Table 2: Results of best fitting linear models relating management and habitat variables to (a) average richness, (b) farm uniqueness for plants, earthworms, spiders and bees and (c) the mean average richness and the mean farm uniqueness over all four taxonomic groups and the total mean on 19 farms (Est. = estimated regression coefficient, *p* = *p*-value). Significances are printed in bold.

		Organic vs. non-organic farming		Average stocking rate [LU/ha]		Expenditures [€/ha]		Nitrogen input [kg/ha]		# of mechanical operations		# of areal habitat types		# of linear habitat types		Average size of habitats [ha]		R^2 adjusted of final model
		Est.	*p*	Est.	*p*	Est.	*p*	Est.	*p*	Est.	*p*	Est.	*p*	Est.	*p*	Est.	*p*	
(a)	Plants									**-0.037**	**<0.001**							0.536
	Earthworms							**0.002**	**0.008**			**0.119**	**<0.001**			**0.00007**	**0.007**	0.598
	Spiders															-0.0001	0.053	0.156
	Bees									-0.039	0.066							0.138
(b)	Plants											**0.262**	**<0.001**					0.701
	Earthworms	**-0.424**	**0.023**	**-0.406**	**0.035**													0.258
	Spiders													**0.236**	**0.002**			0.409
	Bees	**0.488**	**0.010**			**-0.001**	**0.008**	**-0.004**	**0.021**							**-0.0002**	**0.001**	0.658
(c)	Mean average richness[1]									**-0.021**	**0.004**							0.351
	Mean farm uniqueness[1]											**0.110**	**0.002**	**0.117**	**0.008**			0.662
	Total mean											**0.073**	**0.002**	**0.061**	**0.030**			0.619

[1] Over the four taxonomic groups

3.3. Relevance of habitat categories

Each of the four aggregated habitat categories had specific importance for the taxonomic groups (Fig. 3). Low-input areal habitats had a high average richness of plants and bees, a high habitat uniqueness of bees and a very high habitat uniqueness for plants. Intensively managed areal habitats were the favourites of earthworm species regarding both metrics. Linear habitats, especially those with woody structures, were the most important for spiders, also regarding both metrics. The means over all four taxonomic groups compensated the differences among the groups. Intensively managed areal habitats were by far the most frequent of the four habitat categories. Despite this, it had the lowest mean average richness ($F = 0.840$, p-value = 0.498) and mean habitat uniqueness ($F = 0.341$, p-value = 0.796). Mean average richness was highest for low-input areal habitats. Mean habitat uniqueness was highest for linear habitats with woody structures.

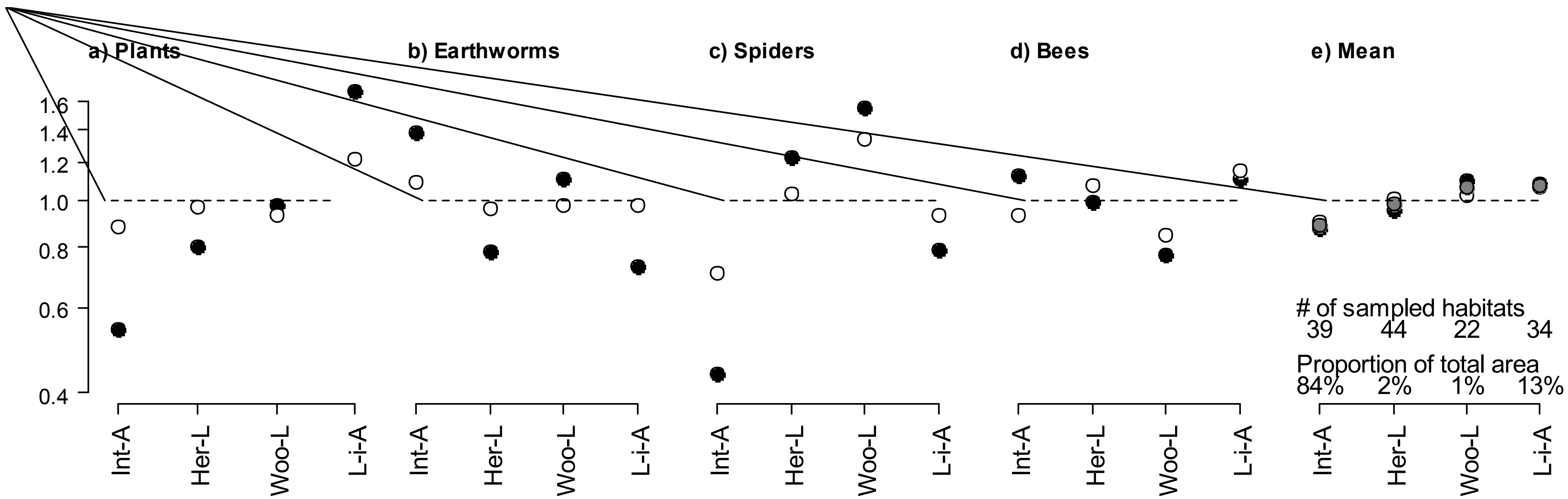

Fig. 3: Species diversity metrics of habitat categories. Average richness (open circles) and habitat uniqueness (filled circles) for (a) plants, (b) earthworms, (c) spiders and (d) bees of four habitat categories: Int-A = intensively managed areal habitats, Her-L = herbaceous linear habitats, Woo-L = linear habitats with woody structures, L-i-A = low-input areal habitats are shown relative to the average of all habitat categories (dashed line). Panel (e) shows the mean average richness over the four taxonomic groups (open circles), the mean habitat uniqueness over the four taxonomic groups (filled circles) and the total mean (grey circles). The *y*-axis is log-scaled to equalize distances below and above the average mean. Habitat categories are ordered according to the total mean.

4. Discussion

4.1. Information about species diversity for farmers

The aim of our study was to devise simple metrics which usefully encapsulate species diversity on farms and supply farmers with quantitative information on biodiversity on their farms. Average richness and farm uniqueness are well-adapted to fulfil most of the criteria postulated in the introduction, namely simplicity, comparability and adaptation to the complexity of biodiversity and farm structures. We propose to provide farmers with an information table on species diversity containing the two farm-level metrics for plants, earthworms, spiders and bees as well as their overall means (Table 3). These eleven values give an amount of information which is easy to overview but still provides some insight into the generating processes (simplicity). The values relate species diversity on the focused farm to species diversity on an average farm in the study region (comparability). The relative nature of the metrics also allows for the assessment of management effects independent of annual fluctuations of populations. Our correlation analysis showed that the two metrics were independent of each other and among the four taxonomic groups (complexity of biodiversity). They convey two aspects of biodiversity: average richness, related to quantity, and farm uniqueness, related to quality. Both aspects are important and should be presented transparently as in Table 3. Finally, the hierarchical assessment method as well as the derived metrics account for the heterogeneity of farm structures (complexity of farm structures). In addition, information may be complemented by the lists of observed species on a farm including their red-list status or other conservational or functional characteristics. Doing so encourages farmers to detect where and why species diversity aspects are well established on their farm and to tap existing potential. We propose to use this information in the context of agricultural consultancy or biodiversity assessments at regional scale.

Table 3: Information on species diversity by the two metrics, average richness and farm uniqueness, of plants, earthworms, spiders and bees and the respective means on three farms of the study region (as example: farm C, H and P, see Fig. 2). Values are given in percentages to the average of the region, i.e. 100%.

Farm	Metric					Mean over the four taxonomic groups	Total mean
C	Average richness	110	80	125	95	103	82
	Farm uniqueness	42	109	68	24	61	
H	Average richness	76	107	82	82	87	89
	Farm uniqueness	77	84	62	143	92	
P	Average richness	112	128	86	112	109	127
	Farm uniqueness	194	118	159	103	144	

4.2. Can general recommendations for species diversity be derived from contrasting taxonomic groups?

In order to account for the complexity of species diversity, we investigated four contrasting taxonomic groups. Plants, earthworms, spiders and bees differ not only in their food and habitat requirements but also in their mobility. These differences were corroborated by almost independent distributions of the two metrics across the investigated farms, with the exception of farm uniqueness of plants and bees. They also explain contrasting responses to management practices and/or habitat characteristics, which affect diversity metrics of, e.g. earthworms and spiders or earthworms and bees in opposite ways. Nevertheless, our analyses showed that a few variables had consistent positive effects on mean average richness and mean farm uniqueness across all four taxonomic groups. These were primarily a high number of different habitat types and a low management intensity. Current Swiss agricultural policies are partly along these lines in compensating farmers for loss of earnings due to less intensive management (OECD, 2011). Our data suggests that such payments are especially beneficial for plants and bees. Since farm uniqueness of plants tended to be correlated to the farm uniqueness of the other taxonomic groups, plants should be assessed as a priority if only one group can be inventoried. This finding supports approaches that use plant species as indicators for farm biodiversity due to limited time and financial resources (e.g. SR-910.14, 2001). Indeed, costs of 1006€ were estimated for the assessment of plant diversity on an average farm, applying the methods described above, as compared to 2332, 1993 and 1438€ for earthworm, spider and bee diversity, respectively (Targetti et al., 2014). Nevertheless, many more taxonomic groups than plants depend on farmland and require specific promotion (Büchs, 2003). For example, as our data showed, spider and bee diversity were promoted by habitat diversity and small-scale heterogeneity. Spiders benefited from linear habitats with a structure-rich vegetation, in line with earlier studies (Gibson et al., 1992; Knop et al., 2006). In addition, small habitat patches contributed significantly to high bee diversity, likely because higher habitat heterogeneity enhanced the chance of continuous food supply and appropriate nesting sites for bees (Kremen et al., 2007). Therefore, creating, maintaining and connecting habitats with structure-rich vegetation and a high flower abundance, will increase species diversity in the study region. This can be best achieved by combining quality assessment and appropriate incentives. In contrast to the other three taxonomic groups, earthworm diversity peaked in the intensively managed areal habitats indicating appropriate soil conditions and sufficient food supply in these grassland fields that nearly exclusively were fertilized with organic nitrogen. Further, deciduous woody habitats contribute considerably to earthworm diversity which was reflected in the high uniqueness of linear habitats with woody structures (Paoletti, 1999).

4.3. Specific recommendations to farmers

Three farms were further scrutinized as representatives for the three groups of farms with specific characteristics, resulting from the cluster analysis. We discuss highlights and potentialities of these farms and make recommendations to enhance species diversity. The information is aimed at being forwarded to the farmers. To be appropriately assimilated by them, communication should be embedded in a familiar environment (Ahnstrom et al., 2009). We suggest providing the information in individual meetings, preferably on the respective farm. Further, group meetings for farmers of the study region would enable additional exchange of knowledge and practical recommendations (Burton et al., 2008).

Farm C, to begin with, had intermediate average richness across all taxonomic groups but only 61% farm uniqueness of the regional average. This indicated that large areas of this farm mostly contained common species, but the total number of species and/or the number of rare species were low. A closer examination revealed that farm C had only four different habitat types (one intensively managed areal habitat, one low-input areal habitat and two types of grassy linear habitats). To increase its species diversity, farm C should integrate new habitat types, e.g. hedgerows, in order to create new environmental conditions favourable to particular species (Concepción et al., 2012).

On farm H, both mean average richness and mean farm uniqueness over the species groups were close to the average (87% and 92%, respectively). However, while the average richness and farm uniqueness of plants, earthworms and spiders were close or below the average, farm uniqueness of bees was strikingly high (143%). This can be explained by the presence of a steep meadow with several patches of bare ground and intensive insolation, which was attractive for many ground-nesting bees and their cuckoo bees. The conservation of this habitat is crucial for the farm’s bee diversity. Moreover, our data suggest a reduction of mechanical field operations to enhance plant average richness.

The mean average richness and the mean farm uniqueness of farm P were above average. This was mainly due to the very high farm uniqueness of plants (194%) and the high farm uniqueness of spiders (159%). These two taxonomic groups benefited from the high number of different habitat types on this farm. However, the lower average richness of plants and spiders and the high average richness and farm uniqueness of earthworms indicated relatively high management intensity and large habitat patches. Knop et al. (2006) found that a reduction of mechanical field operations, e.g. a lower cutting frequency and a staggered cutting benefited species diversity. Such management changes are expected to be beneficial for species diversity on farm P, too.

4.4. Contribution to biodiversity promotion on farms by providing scientific information

Providing information about species diversity on farms is one essential step to promote biodiversity on farmland (Home et al., 2014). However, delivering information alone is not sufficient for a fundamental shift in farmland management priorities. To halt the loss of biodiversity in farmland, the cooperation of numerous actors (e.g. authorities, consumers, marketers, farmers or scientists) is crucial (Moon et al., 2012; Siebert et al., 2006). As farmers are key players in their sphere of influence, they have to be involved in knowledge exchange first of all (Burton et al., 2008; Greiner and Gregg, 2011). Scientists have different approaches to and perspectives for biodiversity than farmers (Clark and Murdoch, 1997). Scientists are engaged in detecting secrets in the fascinating diversity of life and rising awareness for the intrinsic value of biodiversity. They may assess the monetary and non-monetary values of ecological functions provided by biodiversity, and reveal the importance of ecosystem services such as soil fertility, pollination and biological control of pests. Hence, scientists can provide recommendations for a collaborative solution process by emphasizing aspects of biodiversity that play a key role for agriculture. We see a high potential for improving the effectiveness of existing recommendations and policies for biodiversity-friendly management if scientists succeed in better informing farmers about biodiversity on their land. The two metrics of species diversity proposed here aim at highlighting the biodiversity “hot spots” on farms and at motivating farmers to promote biodiversity. Such concrete metrics are needed, more than top-down enacted measures, to generate interest and motivate changes in agricultural practices (Burton and Schwarz, 2013). Hence, the next step includes the development and implementation of an attractive communication concept for the two metrics.

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Appendix A and B. Supplementary Material

Appendix A

Table S.1: Distinction of habitats based on primary life forms, environment and management observed directly in the field. Int-A = intensively managed areal habitats, Her-L = herbaceous linear habitats, Woo-L = linear habitats with woody structures, L-i-A = low-input areal habitats.
* Classification in different habitat categories based on precise management information.

Habitat type	Number	Areal/Linear	Habitat category
Grasses and herbs on mesic, eutrophic soil	37	areal	Int-A/L-i-A *
Traditional orchard	8	areal	Int-A
Grasses and herbs on mesic, neutral soil	7	areal	L-i-A
Grasses and herbs on mesic, eutrophic soil; 1 – 10% tree cover	6	areal	Int-A
Grasses and herbs on dry, eutrophic soil	5	areal	L-i-A
Herbs (at least 70% of cover) on mesic, eutrophic soil	4	areal	Int-A/L-i-A *
Grasses (at least 70% of cover) on mesic, eutrophic soil	1	areal	Int-A
Grasses (at least 70% of cover) on mesic, neutral soil	1	areal	L-i-A
Grasses (at least 70% of cover) on wet, eutrophic soil	1	areal	L-i-A
Grasses and herbs on mesic, acid soil; 1 – 10% tree cover	1	areal	L-i-A
Grasses and herbs on wet, eutrophic soil	1	areal	L-i-A
Shrubs (0.05 – 0.3 m)	1	areal	L-i-A
Herbaceous strip	29	linear	Her-L
Species poor hedgerow	12	linear	Woo-L
Private roads and tracks with herbaceous verges	9	linear	Her-L
Species rich hedgerow	9	linear	Woo-L
Grassy strip	4	linear	Her-L
Unpaved tracks	2	linear	Her-L
Line of trees	1	linear	Woo-L

Appendix B

Table S.2: Example for the calculation of the farm uniqueness of three farms. (a) Number of observations of species *i* in farm *j* and the number of habitat types in farm *j,* (b) The mean number of observations of species *i* per habitat type in the farm and weight of the farm proportional to its number of habitat types (ω_j); (c) Weighted mean number of observations of species per farm and sum of them per species; (d) Specificity of species *i* to farm *j* ($\sum_j \omega_j \overline{x_{hij}}$) and uniqueness of farm *j* ($FU_j = \sum_i \frac{\omega_j \overline{x_{hij}}}{\sum_j \omega_j \overline{x_{hij}}}$, Wagner and Edwards, 2001).

(a)	Sp 1	Sp 2	Sp 3	Sp 4	Sp 5	# of habitat types (in farm)
Farm A	9	5	2	1	1	3
Farm B	3	3	0	2	0	2
Farm C	10	7	4	0	5	4

(b) $\overline{x_{hij}}$	Sp 1	Sp 2	Sp 3	Sp 4	Sp 5	ω_j
Farm A	3.000	1.667	0.667	0.333	0.333	0.333
Farm B	1.500	1.500	0.000	1.000	0.000	0.222
Farm C	2.500	1.750	1.000	0.000	1.250	0.444

(c) $\omega_j \overline{x_{hij}}$	Sp 1	Sp 2	Sp 3	Sp 4	Sp 5
Farm A	1.000	0.556	0.222	0.111	0.111
Farm B	0.333	0.333	0.000	0.222	0.000
Farm C	1.111	0.778	0.444	0.000	0.556
$\sum_j \omega_j \overline{x_{hij}}$	2.444	1.667	0.667	0.333	0.667

(d)

$\frac{\omega_j \overline{x_{hij}}}{\sum_j \omega_j \overline{x_{hij}}}$	Sp 1	Sp 2	Sp 3	Sp 4	Sp 5	$FU_j = \sum_i \frac{\omega_j \overline{x_{hij}}}{\sum_j \omega_j \overline{x_{hij}}}$
Farm A	0.409	0.333	0.333	0.333	0.167	1.576
Farm B	0.136	0.200	0.000	0.667	0.000	1.003
Farm C	0.455	0.467	0.667	0.000	0.833	2.421
Sum						5